

Proceedings of the 26th Nordic Seminar on Computational Mechanics

A. Logg, K.A. Mardal (Eds.)

©Oslo, 2013

Modelling ship grounding with finite elements

Ole J. Hareide¹, Lars Brubak^{1,2}, and Torstein Pettersen¹

⁽¹⁾Section for Ship Structures and Concepts, Maritime Advisory, Det Norske Veritas, Norway.

E-mail: ole.jakob.hareide@dnv.com

⁽²⁾Mechanics Division, Department of Mathematics, University of Oslo, Norway

Summary. Numerical simulations using non-linear finite element analysis have been performed to study ship grounding. The results are compared with experimental tests which were performed in USA in 1995 and good agreement is achieved. This illustrates that nonlinear FE analysis can be used to estimate damage extent from a grounding scenario.

Key words: Ship grounding, FEA, non-linear analysis

Introduction

Every year ships run aground around the world. The potential for damage is huge, both in economic and ecological terms. With the ability to simulate ship groundings with finite element software and assess the strength of a ship against such incidents there is a huge potential to be gained. Similar studies for collision scenarios by using nonlinear finite element analysis have been performed by Notaro et. al [2, 1]

A detailed picture of a ship's performance in a grounding situation can be used in the design of the ship. The results do, however, depend on correct material parameters and the use of a correct coefficient of friction in addition to a very detailed description of the geometry. There is not much data to be found from real events so to verify that the model is indeed giving reasonable results, a series of analyses has been run against results obtained from scale tests performed in the USA in 1995 [4].

Background

A series of model scale test was performed at the Naval Surface Warfare Center in the US in 1995. Four different steel configurations of double bottom structures were built in 1:5 scale and used to evaluate the performance when impacted into a concrete cone used to simulate a rock on the seabed. The models were mounted to a rail cart and released down a slight incline in order to build up velocity and hit the rock at a speed of 14 knots. In a double hull configuration there is generally not a danger for a cargo spill if the inner hull is not breached, so the double bottom models were mounted at a pitch angle of approx. 3.2° in the test rig to ensure a gradual vertical increase in the damage depth and eventually a rupture of the inner hull. The output from the experiments, which have been used to compare the finite element results against, were force-displacement and energy-displacement curves.

FE model and analysis procedure

A detailed model of one of the double bottom scale models was created in Abaqus/Explicit v6.11 [3]. Of the four models tested the one chosen for modelling in Abaqus was the configuration

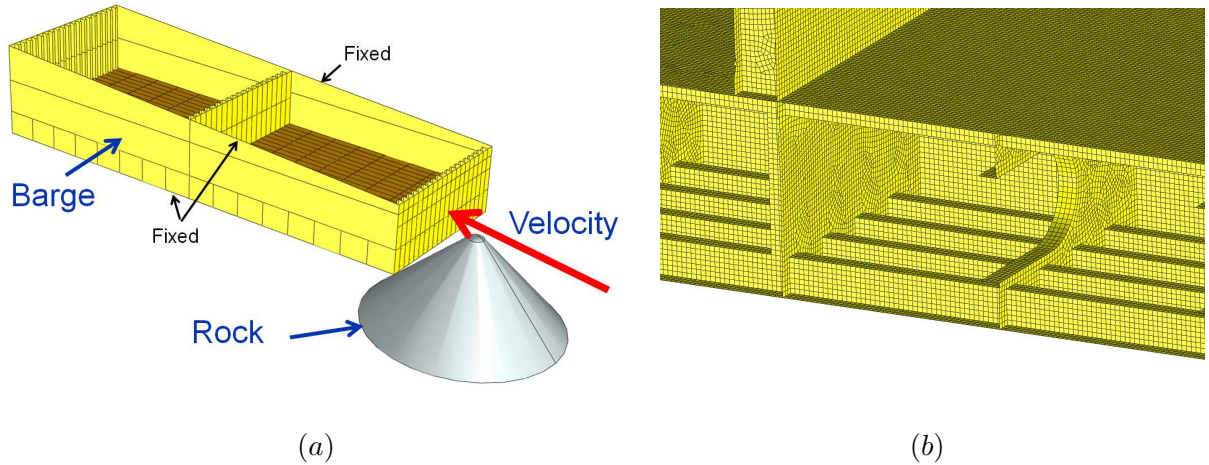


Figure 1. (a) A barge impacting into a rock and (b) the detail level and mesh for the barge where stiffeners, girders and bulkheads are included.

most resembling the double bottom of a traditional tanker as shown in Fig. 1. The model consisted of two cargo holds divided by a stiffened bulkhead. On either end of the hold there were also stiffened bulkheads. The double bottom consisted of a longitudinal girder in the centre and seven transverse frames under each hold. The rock was modelled as a rigid body with a cone shape.

First-order reduced-integration shell elements were used with a fine mesh size of around 10x10mm in a fine area where the rock would impact and 50mm in the rest of the model. The reason for such a fine mesh, which is in the order of three times the thickness, is to accurately capture the failure mechanisms such as rupture, folding and crushing of plates and stiffeners.

The material used in the model was an ASTM A569 isotropic steel with a Young's modulus of $E = 206000\text{MPa}$, Poisson's ratio of $\nu = 0,3$ and density of $\rho = 7.9 \times 10^3\text{kg/m}^3$. Plasticity was included with a yield stress of $\sigma_y = 283\text{MPa}$. In order to model the rupture of the steel as the rock passed through the model a tensile failure criterion was added to the material definition which after tensile strain of 0,278 will simulate necking behaviour in the material and linearly degrade an element's stiffness down to zero over a damage displacement, defined here as 3,2mm additional displacement after necking occurs. When the element's stiffness has reached zero it is visually removed from the analysis.

The coefficient of friction is difficult to measure from a grounding experiment due to other energy dissipating mechanisms such as tearing and folding of the structure. Typical values of steel against rock ranging from 0.4 to 0.7 have been used here, and the choice of this coefficient can have a large impact on the dissipation of energy.

The analyses were run with Abaqus/Explicit with an initial velocity of 14 knots applied to the model. Along with the mass of the structure an additional mass was added to the model to account for the weight of the testing rig used in the scale model tests. Using an initial kinetic energy (as opposed to the constant velocity) approach means that the kinetic energy will be dissipated by the impact and that the model will come to a halt when the dissipated energy equals the initial kinetic energy. The upper two longitudinal edges in the structure were fixed in order to keep them rigid during the analysis.

Results and discussion

The results from the analyses are shown here in Fig. 2. Both energy and force curves are plotted against the displacement of a reference point placed in the rear of the model. The kinetic energy

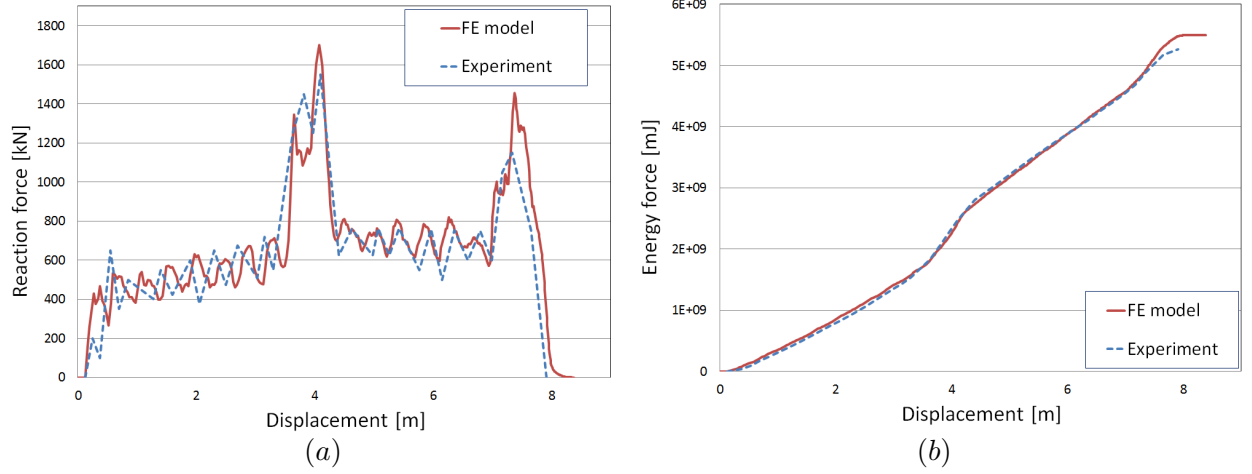


Figure 2. (a) Reaction force and (b) absorbed energy versus the grounding distance.

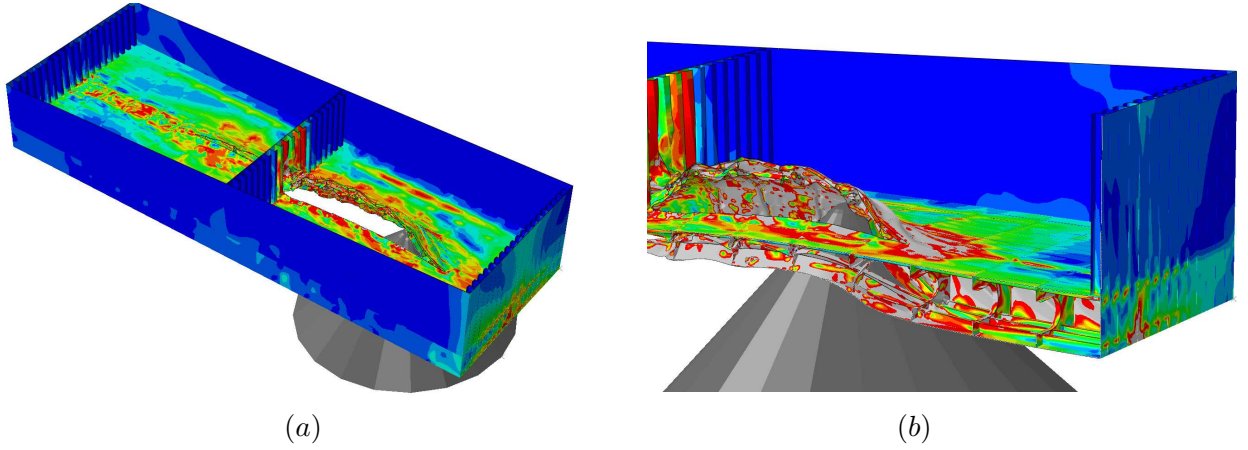


Figure 3. (a) Damage extent of the barge and (b) close-up view of the damages.

will drop as the energy dissipation increases. From the force curve, several smaller spikes and the two large spikes are observed, corresponding to the structure resisting deformations as the rock passes through the several smaller transverse frames and the two cargo hold bulkheads at the center and the aft. There is also an overall increasing trend in the registered force which is due to the pitch angle. The absorbed energy can be found by integrating the reaction force over the grounding distance and thus it can be seen to also have a slightly higher absorption rate (energy absorption pr. meter) around the two bulkheads than in the cargo hold itself.

The total dissipated energy can be broken down into several components such as friction, plastic deformation, elastic strain and energy gone into tearing elements apart. In the analyses that were run it was seen that most of the energy is dissipated by plastic deformation and friction while the other aforementioned energies that make up the rest are relatively small. The ratio between the energy going into friction and plastic deformation varies depending on the coefficient of friction, as was mentioned above.

The damages are shown in Fig. 3 and it can be seen that the deformations are very large. This illustrate that nonlinear finite element computations can be used to estimate the damage extent with reasonable accuracy. From what can be read from the pictures of the experimental test [4], the damages are very similar to what was found in the present finite element analysis. In Fig. 4, close-up views of the deformations in the longitudinal girder and in the area close to the transverse bulkhead are shown.

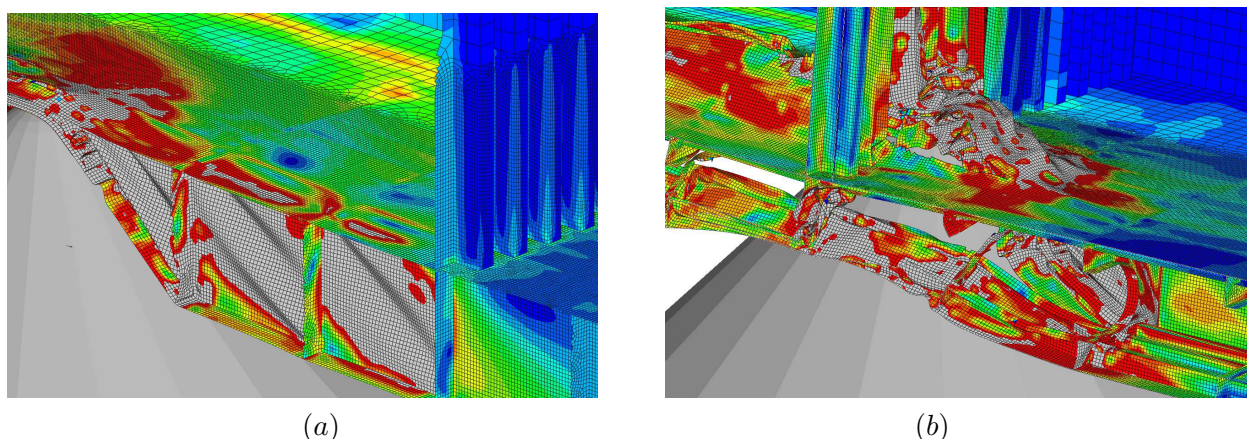


Figure 4. Close-up view of (a) the deformation in the longitudinal girder which is a typical skewed folding pattern from shear deformations and (b) the deformations at the transverse bulkhead.

Conclusion

Finite element analysis for a grounding scenario has been performed and computed results are compared and verified with experimental test data from a steel 1:5 scale model. Results show that the simulation can accurately predict the damage extent and yield the same energy dissipation rate.

Acknowledgments

The authors would like to thank dr. Eivind Steen, Tom K. Østvold, Gabriele Notaro and Alessio Prestileo at Det Norske Veritas (DNV), for their interest, suggestions and valuable discussions throughout the study.

References

- [1] G.Notaro, K. Brinchmann, E. Steen and N. Oma. *Evaluation of the Fendering Capabilities of the SPS for an Offshore Application*, ICCGS 2013 Conference, Trondheim, Norway, 2013.
- [2] G.Notaro, T.K. Østvold, E. Steen and N. Oma. *Collision Damages and Residual Hull Girder Strength of a Ship Shaped FPSO*, PRADS 2013 Conference, Changwon City, Korea, 2013
- [3] ABAQUS/Standard, *User Manual Version 6.11* volume Hibbitt, H. D. and Karlsson, B. I. and Sorensen, I. Hibbit, Karlsson and Sorenson Inc., Pawtucket; 2012.
- [4] James L. Rodd. Observations on Conventional and Advanced Double Hull Grounding Experiments *Proceedings of the International Conference on Design and Methodologies for Collision and Grounding Protection of Ships*. San Francisco, California, 1996